AD-770 140

EXPOSURE OF MAN TO MAGNETIC FIELDS ALTERNATING AT EXTREMELY LOW FREQUENCY

NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY

JULY 1973

Distributed By:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

Unclassified
Security Classification

AD 770 140

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Aerospace Medical Research Laboratory Pensacola, Florida 32512	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A

3. REPORT TITLE

Exposure of Man to Magnetic Fields Alternating at Extremely Low Frequency

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

N/A

5. AUTHOR(S) (First name, middle initial, last name)

Dietrich E. Beischer, James D. Grissett and Robert E. Mitchell

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
30 July 1973	~~32~~ 36	28

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. BuMed MF51.524.015-0013BEOX	NAMRL-1180
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	3

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
N/A	N/A

13. ABSTRACT

Ten subjects were confined for periods up to 7 days and during this time were exposed to a low-intensity magnetic field (10^{-4} Wb/m^2 at 45 Hz) for periods up to 24 hours. Five subjects were confined but were not exposed. A large battery of physiological and psychophysiological tests were given throughout the confinement period. No effects were seen that could be definitely linked with the magnetic field. The only changes that could be correlated with the time course of exposure to the ELF magnetic field were in serum triglycerides of blood samples drawn 14 hours after the evening meal. In 9 of the 10 exposed subjects, serum triglycerides reached a maximum value 24 to 48 hours after the ELF field exposure. Similar trends were not seen in any of the 5 control subjects. For the corresponding period chylomicrons were negligible for all subjects while cholesterol levels were stable and within the normal range; therefore, the serum triglycerides were in the form of very low density lipoproteins. The number of subjects is too small, however, to exclude statistically other factors such as psychophysiological reactions to forced changes in personal living habits, modified activity, restricted diet, and confinement. A final conclusion must await further experiments and the establishment of a relationship between field strength and physiological effects, as well as establishment of a threshold for the effects.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0102-014-6600

I

Unclassified
Security Classification

36

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Magnetic fields						
Alternating magnetic fields						
Extremely low frequency fields						
Electromagnetic environment						
Serum triglycerides						
Hyperlipidemia						
Pre-beta-hyperlipoproteinemia						
Hyperlipemia						

II

Approved for public release; distribution unlimited.

EXPOSURE OF MAN TO MAGNETIC FIELDS ALTERNATING AT EXTREMELY LOW FREQUENCY

Dietrich E. Beischer, James D. Grissett and

Robert E. Mitchell

Bureau of Medicine and Surgery
MF51.524.015-0013BEOX

Approved by

Ashton Graybiel, M. D.
Assistant for Scientific Programs

Released by

Captain N. W. Allebach, MC, USN
Officer in Charge

30 July 1973

Naval Aerospace Medical Research Laboratory
Naval Aerospace Medical Institute
Naval Aerospace and Regional Medical Center
Pensacola, Florida 32512

III

SUMMARY PAGE

PROBLEM

Recent developments in communication systems have generated considerable interest in the physiological and psychological effects of nonionizing radiation. Nonionizing radiation exists in that region of the spectrum in which quantum energy levels are insufficient to remove electrons from their parent atoms. The Biomedical Division at this Laboratory is engaged in a research effort to determine whether man can be exposed safely to electric and magnetic fields in the extremely low frequency (ELF) region of the spectrum.

FINDINGS

Ten subjects were confined for periods up to 7 days and during this time were exposed to a low intensity magnetic field (10^{-4} Wb/m^2 at 45 Hz) for periods up to 24 hours. Five subjects were confined but were not exposed. A large battery of physiological and psychophysiological tests were given throughout the confinement period.

No effects were seen that could be definitely linked with the magnetic field; however, serum triglycerides in most subjects appeared to be affected by some factor or combination of factors associated with the experimental protocol. Serum triglycerides in 9 of the 10 exposed subjects reached a maximum value 24 to 48 hours after the ELF field exposure. Similar trends were not seen in any of the 5 control subjects. The number of subjects is too small, however, to exclude statistically other factors such as psychophysiological reactions to forced changes in personal living habits, modified activity, restricted diet, and confinement. A final conclusion must await further experiments and the establishment of a relationship between field strength and physiological effects, as well as establishment of a threshold for the effects.

ACKNOWLEDGMENTS

The authors are grateful to the technical staff of the Biomedical Division, Messrs. C. S. Ezell and W. C. Hammer, HM2 W. M. Riddle and HM2 J. A. Gaily who assisted in fabrication of the apparatus, conduction of the experiments, and the reduction of data. A special thanks goes to the subjects who volunteered their time and consented to the personal sacrifices and discomforts involved in the collection of the data.

INTRODUCTION

Recent developments in communication systems have generated considerable interest in the physiological and psychological effects of nonionizing radiation. Nonionizing radiation exists in that region of the electromagnetic spectrum in which quantum energy levels are insufficient to remove electrons from their parent atoms. On the frequency scale, the nonionizing range extends from zero to approximately 10^{15} Hz*, slightly above the visible spectrum. The Biomedical Division at this Laboratory is engaged in a research effort to determine whether man can be exposed safely to electric and magnetic fields in the extremely low frequency (ELF) region of the spectrum below 100 Hz. Persinger (23) recently reviewed the psychophysiological effects of ELF electromagnetic fields and reported some physiological effects on animals and man. None were fatal or debilitating, and most of the effects were subtle and were revealed only with sophisticated apparatus and statistical methods.

The exposure of human subjects to ELF fields described in this report was preceded by a number of animal experiments (5,8,9). In these experiments with lower primates, no biological effects of the selected alternating electrical and magnetic fields were observed. The magnetic field strength in the animal experiments was 10 times higher than that in later human exposure, and the animal exposure periods extended up to 6 weeks. Based on this experience, human volunteers were exposed to alternating magnetic field at 45 Hz and a field strength of 10^{-4} Wb/m^2 for periods up to 1 day. The results of a battery of physiological, psychological and clinical chemical tests were negative with one exception: a significant increase of serum triglycerides was observed in man 1 to 2 days after exposure.

The experimental conditions under which this observation was made will be described in detail. Orher test methods which showed negative results will be treated briefly to allow an appreciation of the clinical and physiological approach taken in this study. This pilot study is expected to furnish directions for further, more specific investigations.

METHODS AND PROCEDURE

ELECTROMAGNETIC ENVIRONMENT

The facility for long-term exposure of human subjects to an alternating magnetic field is shown in Figure 1. A large coil system enclosed a 2.4 m x 4.8 m platform. Within this area at one end of the platform was a full bathroom (2.4 m x 1.2 m). Plumbing fixtures, including pipes, were mostly non-metallic; exceptions were valves and connectors so small that induced currents were insignificant. Subjects were confined to the platform for the entire experimental period.

---

*All units and symbols in this report conform to: The International System of Units (SI), NBS Special Publication 330, 1972 edition.

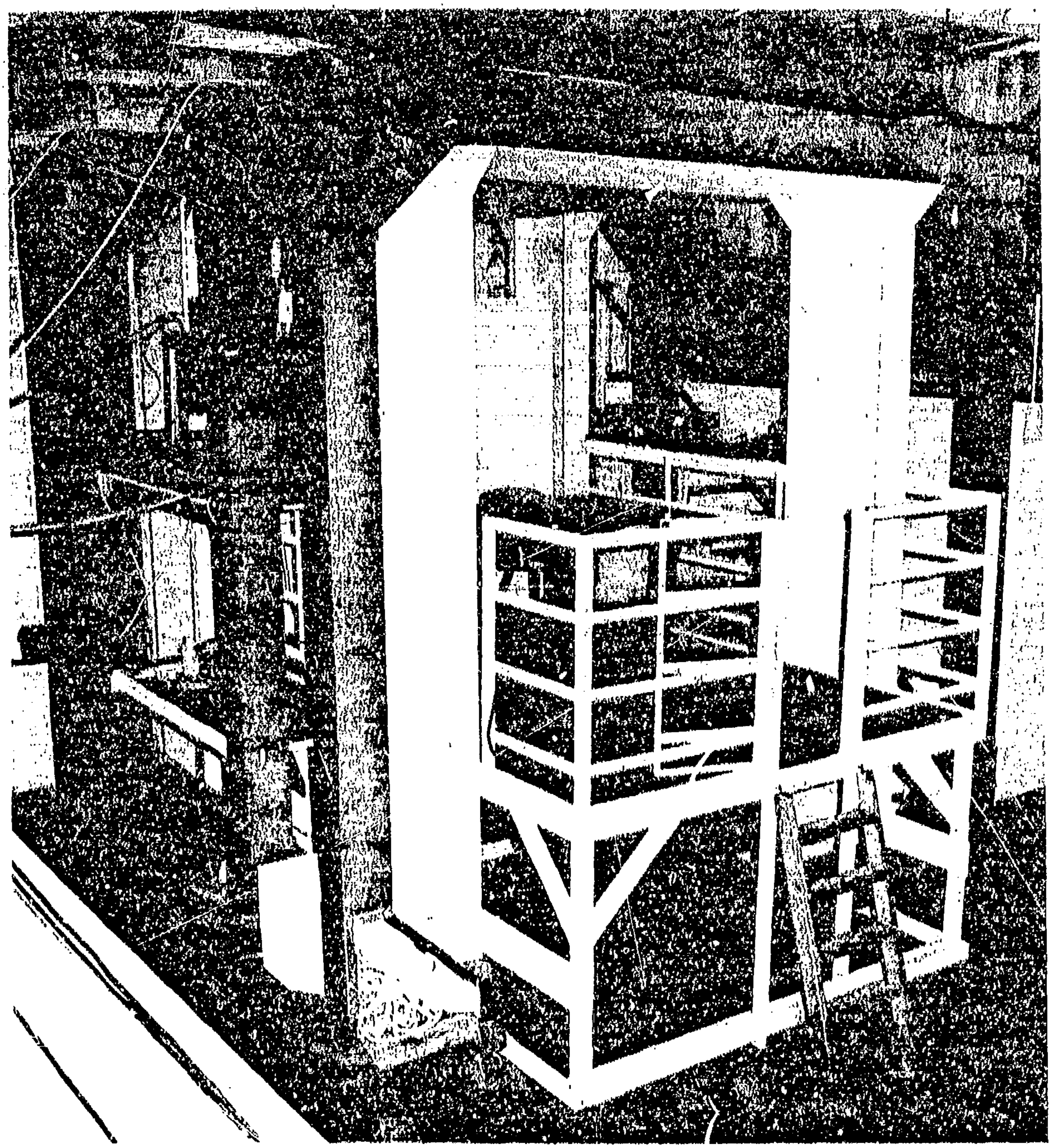

Figure 1

Large coil system at NAMRL that enclosed a subject area 2.4 m x 4.8 m. Within this area at the far end of the platform was a full bathroom (2.4 m x 1.2 m). The coil system that surrounded the platform had four separate coils. With the system energized at 3 A (rms) at 45 Hz, the magnetic flux density was measured at 83 points uniformly distributed over the subject area. The mean flux density was 1.03×10^{-4} Wb/m^2 and the standard deviation was 7% of the mean.

The coil system surrounding the platform was constructed in a square-Barker Four configuration with 3.6 m side lengths. Each outer coil had 72 turns and each inner coil had 32 turns. The outer coils were 0.9 m from the adjacent inner coils, and the two inner coils were separated by 1.8 m. The coils consisted of insulated stranded wire (1/0 AWG, 0.3 Ω/km) wound on a wooden frame.

The system had a total inductance of 0.16 H, and tuning capacitors were required to balance the inductive impedance. Such coil systems are usually tuned by placing a capacitor bank in series with the power source and coil system. Under these conditions, however, an electric field is generated between the coil sections, and the biological effects of the magnetic field cannot be studied separately from the effects of the electric field. The undesirable electric field can be minimized by breaking each coil section at its center and connecting the segments and capacitors in such a way that the electric field generated by each coil segment is canceled by the electric field generated by another segment of the same coil. The construction of large coil systems with minimal electric field interference is described in a separate report (12). The axial electric field in the test facility (Figure 1) was held to 0.08 V/m as compared to the 3.4 V/m field that would have resulted if conventional methods were used. The vertical electric field was 0.1 V/m and was generated primarily by fluorescent lighting fixtures in the building. The walls and roof of the building hat housed the coil system were constructed of sheet metal and grounded to the earth, thus shielding the interior of the building to a certain degree from outside electric fields.

The magnetic field was generated by electric current supplied by a Control System Research DC Servo Amplifier, Model 2000 PRA. The desired frequency and waveform were produced by a Hewlett-Packard Function Generator, Model 203A. The coil system was energized by 3 A (rms) at 45 Hz. The magnetic flux density was measured at 83 points uniformly distributed over the confinement space. The mean flux density was 1.03×10^{-4} Wb/m^2, and the standard deviation was 7% of the mean. The field was in an east-west horizontal direction to minimize interaction with the geomagnetic field which was approximately 0.5×10^{-4} Wb/m^2 in a northerly direction at an angle of 55° below the horizon. The instantaneous field was the vector summation of this steady geomagnetic field and the 45-Hz field.

SUBJECTS

The 13 subjects were Navy men of general good health between the ages of 19 and 28. Subjects MN, PS, SN, and DY were commissioned officers who had been dropped for various reasons from the flight program. Subject PO was an aviation officer candidate who had voluntarily left the flight program. Subjects BR, MY, WD, FA, and LS were aviation officer candidates who were physically unqualified to be aviators, and subjects BN, CS, and RE were Navy corpsmen assigned to this laboratory.

All subjects were given a thorough briefing prior to the experiments and were told the effects previously reported in the literature. The subjects were not pressured in any way to participate; to the contrary, they were specifically asked not to volunteer if they had

any reservations. Those who volunteered signed a consent document, which described the purpose and the procedure of the experiment. The men were given a physical examination that served to screen out subjects having abnormalities that might increase the personal risk or make them unsuitable to participate in any one of the tests. These medical data contributed also to the pre-exposure baseline data.

EXPOSURE PROCEDURE

A total of 13 subjects participated in the study--8 were exposed to the alternating field, and 3 served as controls without exposure. The remaining 2 subjects were exposed to the field in one test run and served as controls in another run. Two exposure times were used: 2 subjects were exposed for 10 hours and 8 subjects for 22.5 hours.

The exposure occurred near the middle of a 1-week period during which the subjects were confined to the large ELF facility. All subjects were told in advance that they would be exposed for a certain time during the confinement period; however, they did not know when the field would be turned on, and clues such as changes in experimental procedure or background noise were carefully eliminated. The five control subjects were unaware they would serve as controls without field exposure.

VITAL SIGNS

Body temperature, heart rate, respiration rate and blood pressure were taken at 0600, 1000, 1400, 1800, and 2200. Blood pressure was measured with an Avionics Research Products Pressurometer, Model 1900. Electrocardiograms were measured with a Hewlett-Packard Model 1514A ECG system.

BLOOD CHEMISTRY ANALYSIS

Fasting (14-hour) blood samples were taken immediately after the subjects were awakened at 0600. A complete blood count and sedimentation rate were determined. The serum was analyzed by autoanalyzer methods (Technicon Analyzers SMA 12/60, 6/60 and AA1). The following determinations were made: total protein, albumin, calcium, inorganic phosphorus, cholesterol, uric acid, creatinine, total bilirubin, alkaline phosphatase, creatine phosphokinase (CPK), lactate dehydrogenase (LDH), glutamic oxaloacetic transaminase (SCOT), chloride, CO_2, potassium, sodium, blood urea nitrogen, glucose and serum triglyceride. Thyroid function was measured indirectly by T-3 uptake and T-4 concentration.

Since the serum triglyceride levels were altered in the exposed subjects, the analytical method is described in detail: The triglycerides were determined by the fluorometric method adapted for the autoanalyzer by Leon, Rush, and Turrell (19). With this method the glycerine is oxidized to formaldehyde and fluorometrically determined as 3,5-diacetyl-1,4-dihydrolutidine. The procedure was supervised by an experienced clinical chemist (Dr. T. E. Wheeler) and with the help of continuous use of standards, the results showed a standard deviation of 7% of the mean.

The so-called "lipoprotein phenotyping" was also carried out. The four major lipoprotein bands were separated by electrophoresis. The relative distribution of these bands and the serum cholesterol and triglyceride measurements were used to determine the phenotype according to the criteria set forth by the World Health Organization (1).

URINALYSIS

All urine output was measured and samples analyzed from collections at 0600, 1000, 1400, 1800, and 2200. Sodium, potassium, creatinine, specific gravity and total urine nitrogen were determined.

RESPIRATORY GAS ANALYSIS

Altmann (2) reported significant changes in the oxygen consumption rate of several animal species during exposure to electric fields; therefore, respiratory gas analysis was included in the test battery to provide an indication of the oxygen consumption rate and the type of metabolites consumed under basal conditions.

Gas samples were taken immediately after the blood samples had been drawn. The subject was recumbent and breathing through a two-way valve. Expired gas was collected in a Douglas bag for 10 minutes. The total expired volume was measured and analyzed by the Haldane method for oxygen and carbon dioxide concentration. From these measurements the oxygen consumption rate and the respiratory quotient were calculated.

PHYSICAL STRESS

The physical stress test was designed to produce a rapid and coordinated cardiovascular, neuromuscular, and metabolic response. ELF field impairment of these systems would be indicated by changes in the cardiopulmonary data collected during this test. Stress was induced by having the subject pedal the ergometer, shown in Figure 2, at 80 revolutions per minute. The face mask contained a Fleisch Pneumotachograph to measure the instantaneous rate of respiratory flow. Two small tubes were mounted axially with the air stream to sample gas flowing through the pneumotachograph. One sample tube was connected to a Beckman LB-1 carbon dioxide analyzer and a second sample tube to a Westinghouse 211M oxygen analyzer. Analog signals proportional to flow rate, carbon dioxide concentration, and oxygen concentration were recorded on magnetic tape. An electrocardiogram (ECG) from chest electrodes was also recorded continuously throughout the test.

The data were recorded for 3 minutes before the subject began exercising. He then exercised for 3 minutes at 65 W. During the next 1-minute rest period, blood pressure was recorded and the workload was increased to 81 W. The subject exercised for 3 more minutes. This sequence continued with the workload being increased in increments of 16 W until the subject's heart rate was between 160 and 180 bpm during the exercise period. In the following 1-minute rest period, the mask was removed. A nose clip was attached and the subject began breathing through a two-way valve. At the end of this

Figure 2

Ergometer used in physical stress test. The face mask contained a Fleisch Pneumotachograph to measure the instantaneous rate of respiratory flow. Two small tubes were mounted axially with the air stream to sample gas for the Beckman LB-1 carbon dioxide analyzer and the Westinghouse 211M oxygen analyzer. All data including an ECG were recorded on magnetic tape.

rest period, he worked at the same load used in the last exercise period. Expired air passed to the atmosphere through a hose and tee valve. After 1 minute of exercise, the subject had purged the hose of ambient air and his heart rate had returned to the range between 160 and 180 bpm. The tee valve was then turned to allow collection (Douglas bag) of all expired gas during the next 3 minutes of exercise. A recovery period followed during which the subject remained seated on the ergometer until his heart rate fell below 100 bpm. The test was given to one subject at 0930 and to the other subject at 1400. The field was turned off for this test, because the 45-Hz magnetic field would have induced a voltage in the ECG electrodes that would have completely masked the ECG recording.

REACTION TIME

Reaction time has been used to study psychophysiological effects of potentially stressful environments. Several investigators, König (16), Hamer (13), and Friedman (6), reported slight changes in human reaction time during exposure to ELF fields below 10 Hz. A new technique to measure and analyze reaction time was developed in this laboratory (11) (Figure 3). The stimulus was a 1000-Hz audio tone presented bilaterally to the subject by a set of earphones. When he heard the tone, he opened a switch that was normally closed. The tone stopped when the switch was opened, and the time interval between onset and termination of the tone was measured and recorded as reaction time for one trial. The trials were repeated at random intervals between 0.8 and 4.0 seconds until the results from 300 trials were accumulated by a Hewlett-Packard 5451A Fourier Analyzer. The probability density function was then computed and plotted as shown in Figure 4. The arithmetic mean and 20 probability points at 5% increments were computed to the nearest millisecond and printed on a teletype. The entire procedure from the first stimulus to the last bit of printed data required less than 20 minutes.

The value for the first 5% increment is a measure of the subject's fastest reaction time. It is more stable than any of the other parameters and depends on the state of physiological factors such as conduction velocity and synaptic delay. The 95% increment is a measure of the subject's slowest reaction time. It is more variable than any of the other parameters and depends on the state of psychophysiological factors such as alertness and concentration. If the subject maintains a high degree of alertness and concentration throughout the session, he will produce a response pattern similar to that shown at the top of Figure 4. If he is not alert or cannot concentrate on the task, he will produce a pattern similar to that at the bottom of Figure 4. Most subjects have response patterns between these two extremes. During the present experiment, each subject was tested between the hours of 0730 and 0830 and between 1230 and 1330 daily.

PUPILLOGRAPHY

The continuous measurement of pupil diameter in response to a light flash has been applied clinically to identify certain neurological disorders (20). In recent years continuous measurement without a flash had been used to evaluate fatigue states or the ability to remain alert (27,28). The underlying theory for this application is that pupil

Figure 3

Reaction time test. The subject opened a switch in reaction to a stimulus, a 1000-Hz tone. The time interval between stimulus and reaction was recorded. Trials were repeated at random intervals between 0.8 and 4.0 seconds until the results of 300 trials had accumulated. The mask served only to reduce visual distractions.

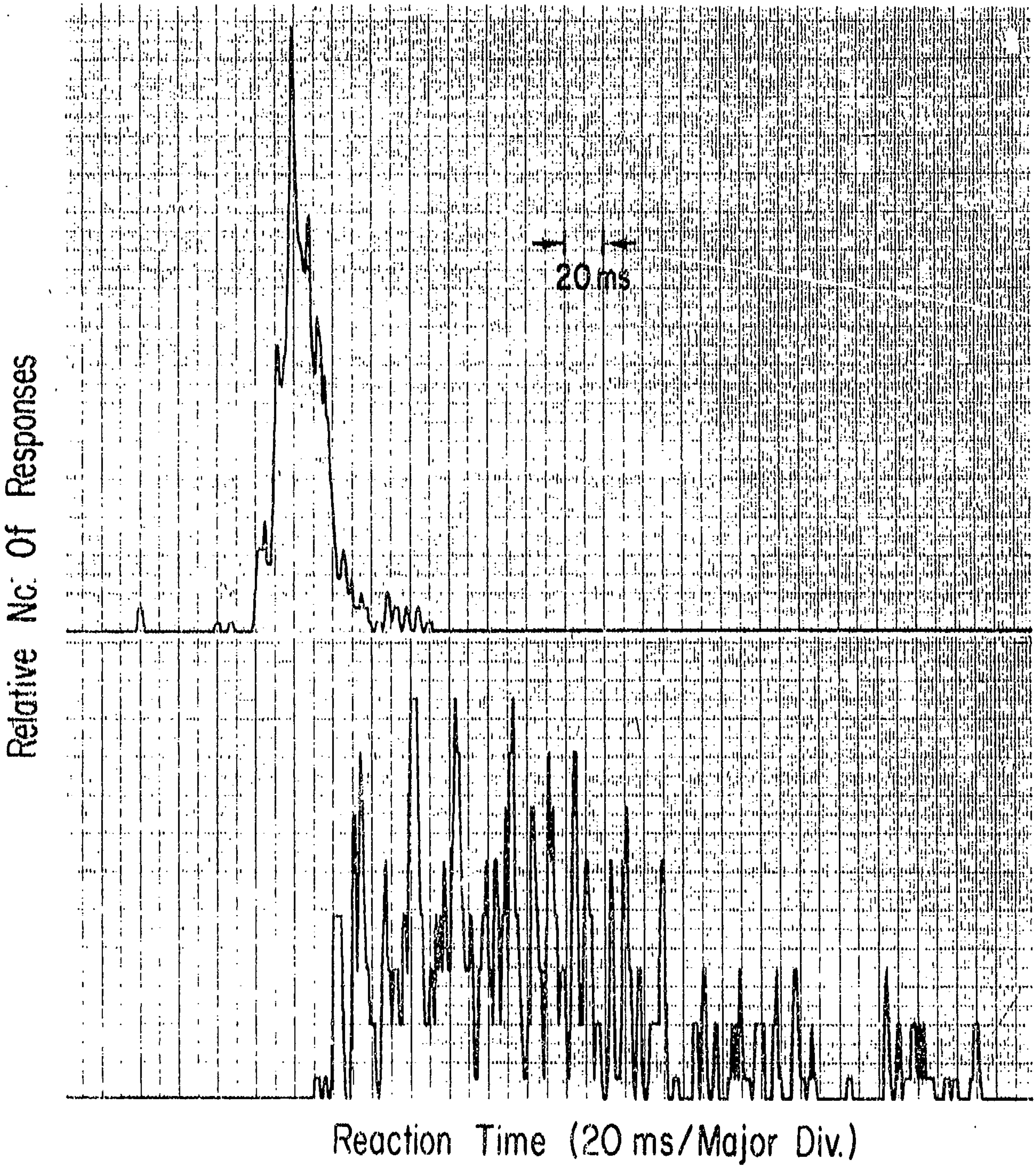

Figure 4

Reaction time test. The reaction time patterns in the top portion show a subject who was alert and concentrating on the task, the patterns in the bottom portion show a subject who was drowsy and fatigued and could not maintain a high level of concentration. Most subjects have response patterns between these two extremes. The minimum reaction times are primarily a function of physiological factors; the maximum reaction times indicate the extent to which psychological factors are involved in the reaction process.

diameter is determined by the antagonistic relationship between the radial and sphincter muscles of the iris. These muscle groups are respectively innervated by nerve fibers from the cervical sympathetic ganglion and the oculomotor nucleus. During periods of arousal, sympathetic stimulation increases while parasympathetic outflow from the oculomotor nucleus is inhibited. Conversely, during periods of drowsiness, sympathetic activity decreases and parasympathetic activity increases. These activity changes in the autonomic nervous system can be demonstrated in a continuous recording of pupil diameter. If a fatigued subject is seated quietly in a darkened room, the pupil diameter will gradually decrease as autonomic activity becomes more parasympathetic and less sympathetic. The decline in pupil diameter may be interrupted by periods of arousal followed by gradual decline. Recordings of these reduced pupil diameters may also contain rhythmic waves with a duration between 2 and 10 seconds and an amplitude usually less than 1.5 mm. Yoss, Moyer, and Hollenhorst (28) used pupil diameter and these spontaneous waves to classify progressive stages from alertness through drowsiness to sleep.

In this series of experiments, pupil diameter was measured by a Whittaker TV Pupillometer Model 800 shown in Figure 5. A television camera and an infrared light source were attached to the same mechanical supports. They were adjusted to provide maximum illumination at the focal point of the lens. The entire support could be moved horizontally and vertically to fix the subject's eye at the focal point. The video output of the camera was transmitted to a monitor containing additional electronics to measure the maximum diameter of the pupil. An analog output proportional to pupil diameter was available from the monitor unit and was recorded continuously throughout a 15-minute test session.

A complete recording from a measurement session is shown in Figure 6. At the beginning of this session the subject's pupil diameter was fairly stable at 6 mm. During the third minute the diameter decreased and pupillary waves began to appear. The decrease continued to approximately 4 mm and the amplitude of the pupillary waves increased. After 11 minutes, ptosis occurred. The remaining record is a cyclic repetition of spontaneous recovery, gradual decline with ptosis, and spontaneous recovery. Each subject was tested between the hours of 0730 and 0830 and between 1230 and 1330 each day of confinement.

SCOTOPIC CRITICAL FLICKER FREQUENCY (SCFF)

The apparatus and technique for measuring SCFF was developed at this laboratory (10). The procedure was included in this test battery because it is a broad spectrum indicator of central nervous system stress. A block diagram of the apparatus is shown in Figure 7. An electroluminescent lamp provided a uniform light source subtending a large visual angle. The voltage-controller oscillator modulated the lamp and provided a constant rate of frequency advance from a randomly selected starting point up to the subject's threshold. The pulse generator was triggered at 4.5-second intervals by a rate generator. The 2.5-second pulse raised the oscillator frequency above the subject's threshold without changing the intensity of the stimulus, thus the subject could compare a flicker and fused condition continually throughout the measurement period. At the beginning of the

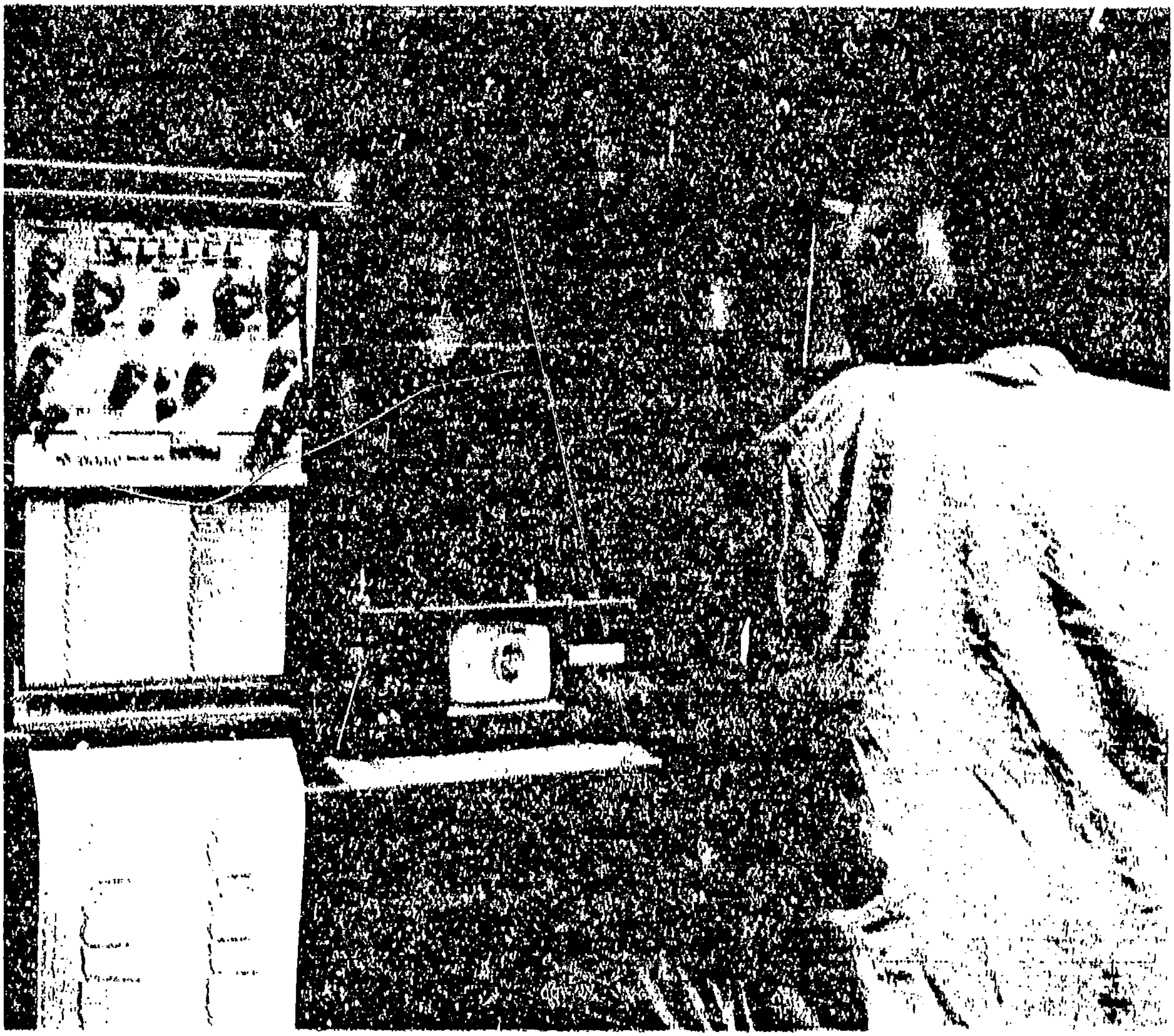

Figure 5

Pupillometry test. The pupillometer consisted of a television camera and an infrared light source attached to the same mechanical supports. They were adjusted to have maximum illumination at the focal point of the lens. The video output of the camera was connected to a monitor containing additional electronics to measure the maximum diameter of the pupil. An analog output proportional to pupil diameter was available from the monitor unit and was recorded continuously throughout a 15-minute test session.

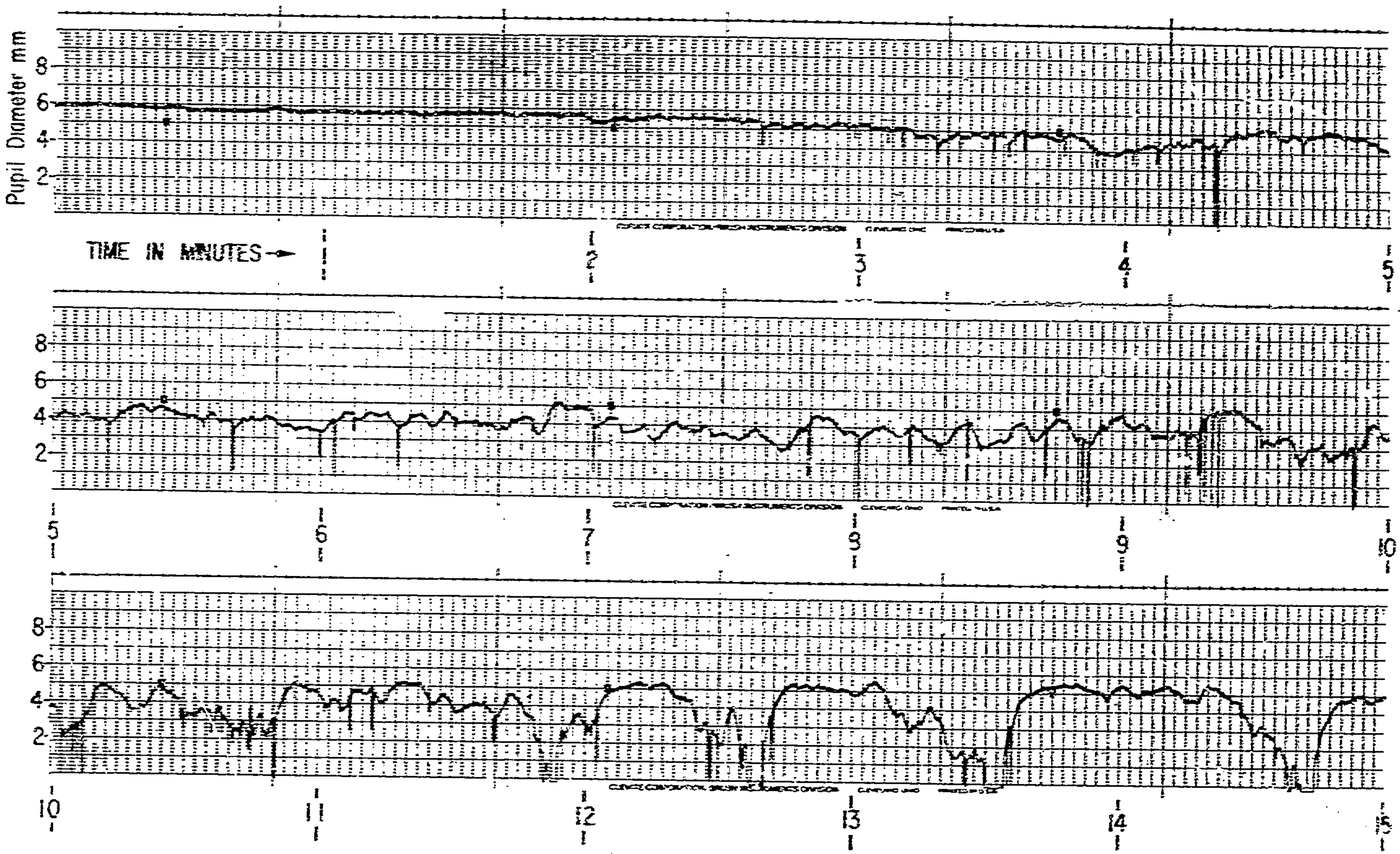

Figure 6

Pupillographic record of a 15-minute session. Pupil diameter was fairly stable for the first 2 minutes. During the third minute, the pupil diameter decreased and pupillary waves began to appear. The decrease continued to approximately 4 mm and the amplitude of the pupillary waves increased. After 11 minutes ptosis occurred. The remaining record is a cyclic repetition of spontaneous recovery, gradual decline with ptosis, and spontaneous recovery.

2-second flickering period, the subject tapped a remote reset switch, which caused the waveform period to be measured by the electronic counter and recorded by the digital recorder. The sequence continued until the lower flicker frequency also exceeded the subject's threshold. The last entry on the recorder was the period of the highest frequency for which the subject detected flicker. This test was given between the hours of 0730 and 0830 and between 1230 and 1330 daily.

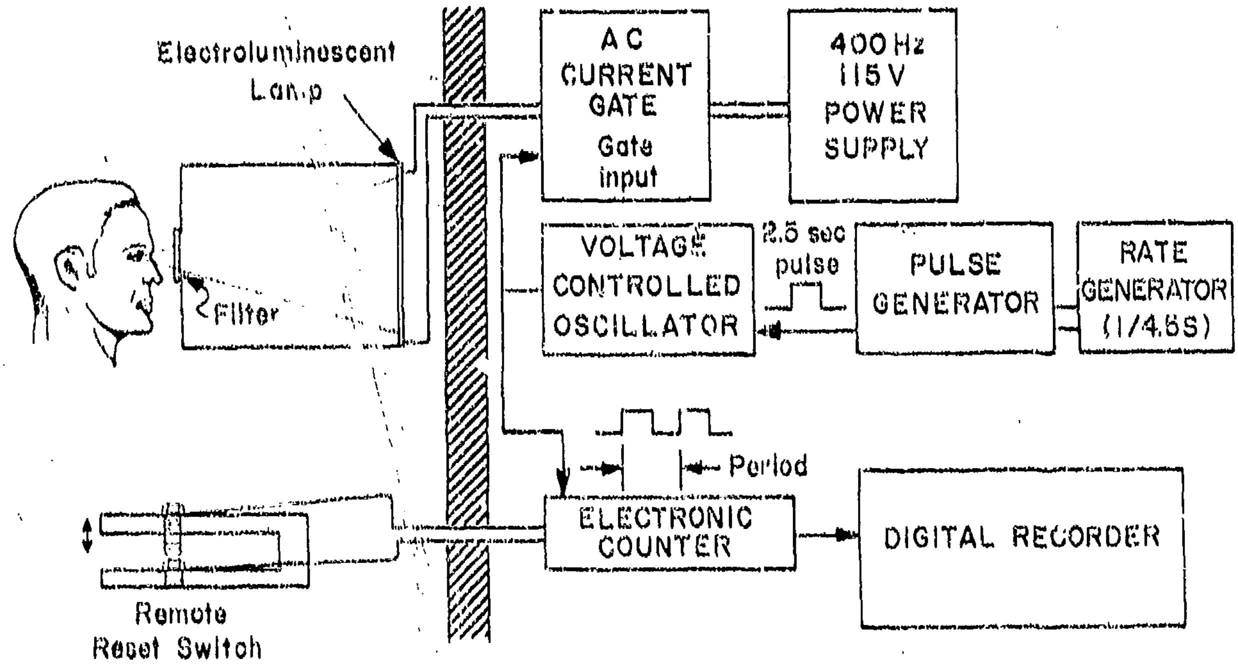

Figure 7

Block Diagram of Apparatus Used to Measure Scotopic Critical Flicker Frequency

PSYCHOLOGICAL TESTS

The following tests were given in cooperation with the Aerospace Psychology Department at this Laboratory. Each test was performed twice daily and the sessions began at 1030 and 1500 hours. The test procedure is included to provide the reader with an appreciation of the approach; however, the data were analyzed by the Psychology Department and the results will be presented in a separate NAMRL report.

SHORT-TERM MEMORY

General Dynamics' Response Analysis Tester (RATER), Model 3 (Figure 8), was used to appraise time for decision making and short-term memory. The subject's portion of the apparatus is shown on the right and consisted of a display screen with four response keys. The operator's console is shown on the left, but it was remote from the subject during testing. The test was given for four modes of operation. All modes required the subject

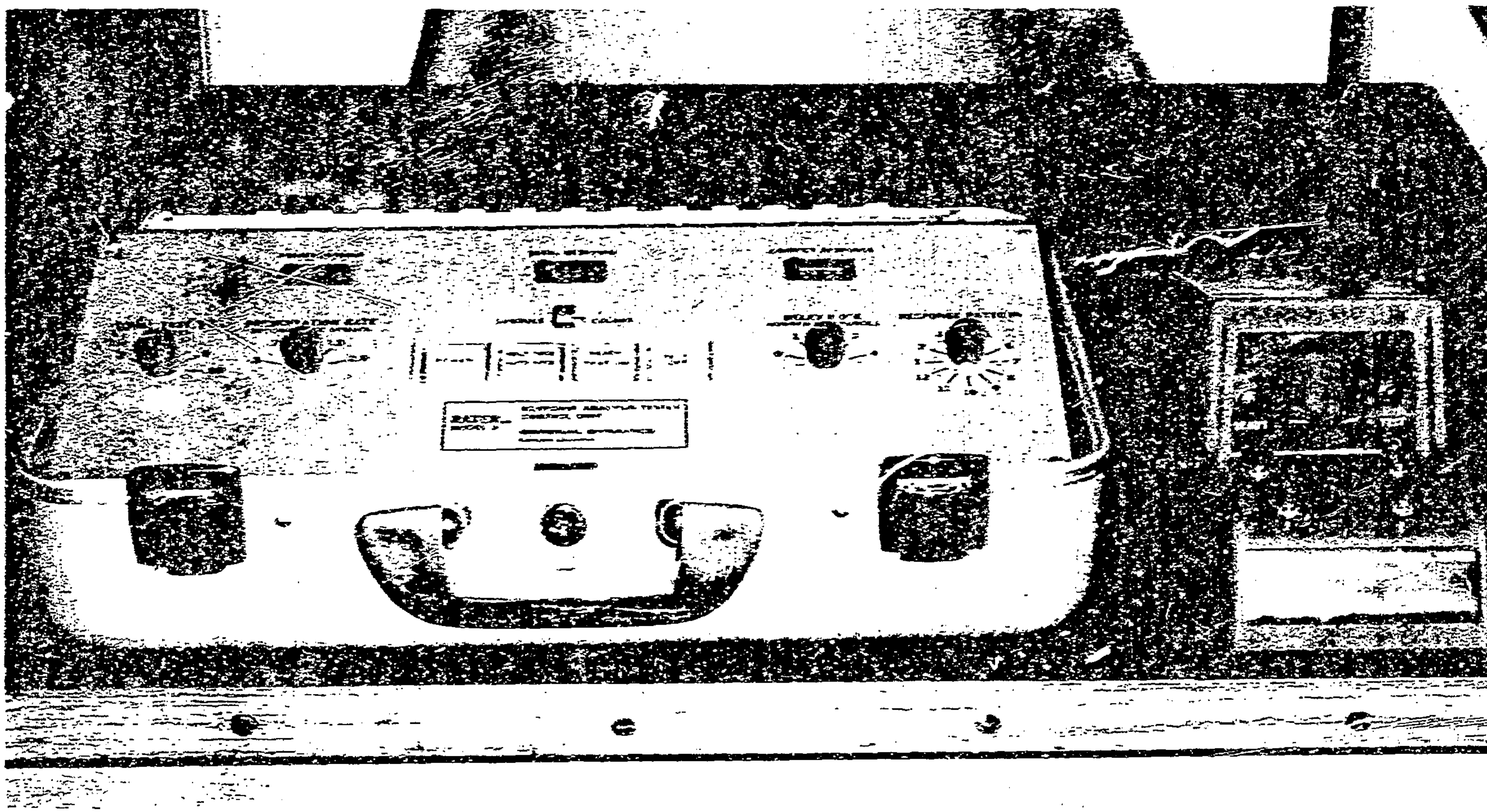

Figure 8

The Response Analysis Tester (RATER) was used to measure time for decision making and short-term memory. The subject's console on the right consisted of a display screen and four response buttons. The operator's console on the left provided mode selection, timing, and scoring. Subject and operator consoles were separated during testing.

to match one of the response keys to one of four possible symbols (plus, circle, square, triangle) as each was projected in a random sequence on a back-lighted screen. In the self-pace mode a new symbol was presented after the subject's correct response. In the auto-pace mode a new symbol was presented every 1.5 seconds and the subject had to respond within this time. In the auto-pace-delay-one mode the subject pressed the key corresponding to the symbol presented prior to the current presentation. In the auto-pace-delay-two mode the subject pressed the key corresponding to the second presentation prior to the current presentation. In the auto-pace-delay-three mode, the subject pressed the key corresponding to the third presentation prior to the current presentation. Each testing mode required 1 minute. The subjects were scored for total presentations, total responses, and correct responses.

TRACKING

Coordination in continuous mode was tested in a tracking task. The subject's portion of the apparatus is shown in Figure 9. The meter needle was normally centered on the scale. In operation, it was continuously driven from this position by electronic circuits in the operator's console. By appropriate right and left movements of the control stick the subject could counterbalance the electronic drive voltage and maintain the needle at or close to the center of the scale. To determine the subject's score, the deviation of the needle from the centered position was integrated over a 1-minute period. The test was given four times at one session, and for one of these trials the required direction for moving the stick in response to a needle movement was reversed. In all cases the magnitude of the score was inversely proportional to the subject's ability to keep the meter centered.

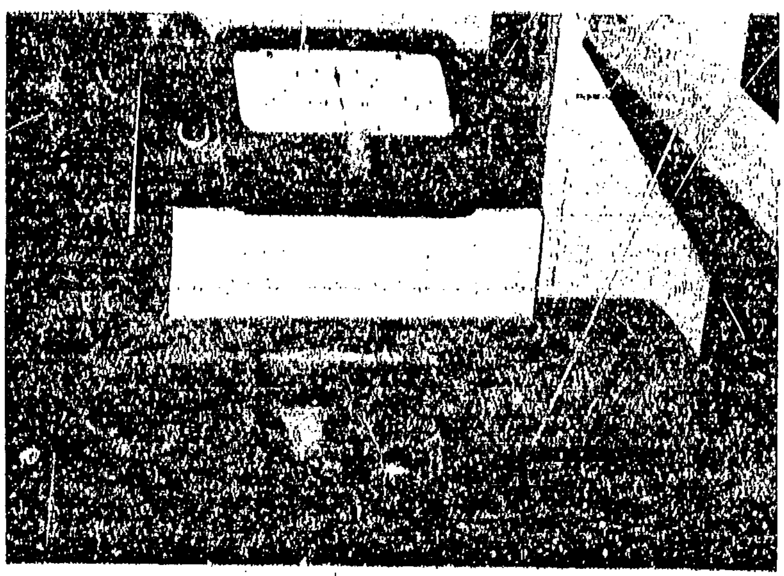

Figure 9

Tracking apparatus. By movements of the control stick, the subjects could correct the electronically driven needle to the zero position of the scale. Score was inversely proportional to deviations from zero position.

MINNESOTA RATE OF MANIPULATION TEST

The Minnesota Rate of Manipulation Test is a measure of discrete mode coordination (eye-hand). The subject turned over as rapidly as possible the set of 60 blocks shown in Figure 10. The elapsed time for this operation was recorded. The test score was the total number of seconds required to repeat this test four times.

WILKINSON ADDITION TEST

The Wilkinson Addition Test was included to indicate changes in the subject's cognitive reasoning and concentration. The subject was required to add columns of five 2-digit numbers in a working period of 5 minutes. The score was based on accuracy and number of completions.

MULTIPLE AFFECT ADJECTIVE CHECKLIST (MACL)*

The MACL consists of 132 adjectives, factor-analytically demonstrated to measure three traits: anxiety, depression and hostility. The subjects checked all adjectives descriptive of their condition at a specified time each day of the experiment. Three trait scores were obtained by summing the responses coincident with a scoring key provided for each trait dimension.

RESULTS

Although each test was described separately in the methods section, the results of several tests were combined to make a more logical and concise presentation. The experimental data were voluminous and will not be presented in this report in their full extent. However, special attention will be given to the results on serum lipids.

VITAL SIGNS

Data for heart rate, blood pressure, body temperature, and respiration rate of all participants were plotted throughout the confinement period. All amplitude variations were within normal range and no significant changes in circadian rhythm were seen in participants exposed to the ELF field.

BLOOD AND URINE ANALYSIS

Both control and exposed participants showed similar variations in their blood analysis. The only changes that could be correlated with the time course of exposure to the ELF magnetic field were those in serum triglyceride levels and pre-beta-lipoproteins. Chylomicron concentrations were negligible throughout the experiments while cholesterol

----

*MACL is authored by M. Zuckerman and B. Lubin and is published by Educational and Industrial Testing Service, San Diego, California.

Figure 10

Minnesota Rate of Manipulation Test

levels were within the normal range and relatively stable throughout the experiments. Under these conditions serum triglycerides were in the form of very low density lipoproteins (VLDL) (1).

The alterations in triglycerides and pre-beta-lipoproteins are described below for each subject in chronological sequence. Changes in the test protocol which became necessary as the pilot experiment proceeded are also pointed out.

The first two subjects, MN and DY, were confined in the coil system for only 3 days. A field of 10^{-4} Wb/m^2 at 45 Hz was turned on the second day between 1100 and 2130 hours. This period was interrupted by a 40 minute-field off time for exercise test between 1320 and 1400 hours. Therefore, the total exposure time was 9 hours 50 minutes or approximately 10 hours. A blood sample was taken at 0600 on the third day or approximately 8.5 hours after exposure. Both subjects showed considerably higher serum triglyceride values for this sample than they had 9 days earlier at the time of their pre-experiment physical examinations. Subject MN changed from 91 to 143 mg/100 ml and subject DY changed from 85 to 170 mg/100 ml while his cholesterol remained normal. In addition DY's pre-beta-lipoproteins increased from 25% to 35%. Subject DY, therefore, changed from a normal lipoprotein phenotype to a Type 4 (pre-beta-hyperlipoproteinemia) (1). These findings provided the first indication that some aspect of lipid metabolism might be affected by an ELF magnetic field.

To examine the lipid metabolism more carefully, it was necessary to prevent wide fluctuations in the subject's diet. It was decided, therefore, to confine future subjects to the coil system for 1 week instead of 3 days and to restrict them to balanced meals prepared by the Naval Hospital, Pensacola. The subjects reported to the test area after their evening meal on Sunday and were confined until noon the following Sunday. The field of 10^{-4} Wb/m^2 at 45 Hz was turned on at 0630 on Wednesday for 24 hours except for two periods of 30 minutes required for the exercise test and one brief period for a 12-lead ECG. Thus, the exposure time was 22.5 hours with a period of 3 days each before and after exposure. During the pre-exposure period the subjects served as their own controls. The subjects were unaware of the actual time of exposure.

The serum triglyceride levels for the first two subjects, SN and PS, under this protocol are shown in Figure 11. When subject SN reported for his initial physical examination 6 days before confinement, his serum triglyceride level was 452 mg/100 ml, which is far above the standard range of 30 to 150 mg/100 ml. Three days before confinement, his serum triglyceride level was 480 mg/100 ml. These values were so high that his suitability as a subject was in doubt, but he was allowed to participate. After confinement on a controlled diet until the exposure began (day 1 in Figure 11), his triglyceride levels decreased at a fairly constant rate. After the field was turned off, this decreasing slope of the triglyceride values was broken and samples taken 24 hours after exposure showed an upward trend. The sample taken 48 hours after exposure again showed a decrease approximately in line with the pre-exposure slope.

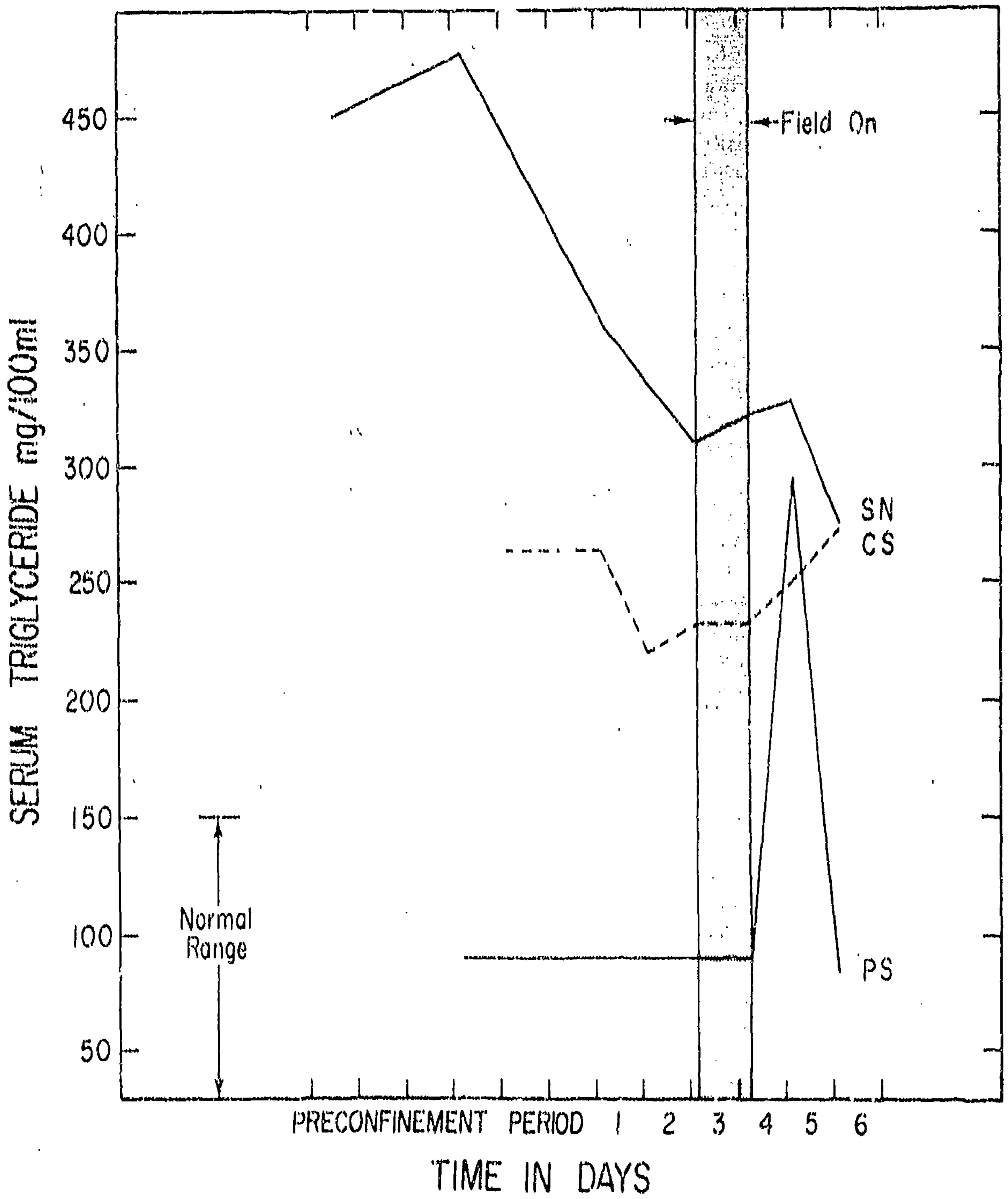

Figure 11

Serum triglyceride levels for one control subject (dashed line) and two exposure subjects. Because subjects SN and CS had unusually high values and subject PS had one high value, their data were plotted on a different scale than that for the remaining subjects shown in Figure 12.

Although the abrupt change in slope of subject SN indicated a field effect, it was not as striking as the data from subject PS which showed a large change 24 hours after the exposure period. This one data point (day 5 in Figure 11) was so far displaced from the other four points that an artifact was suspected. Laboratory error was ruled out, however, because lipemia was visibly apparent and turbidity was 0.87, which indicated abnormal serum lipids. Dietary records revealed nothing to account for this sharp increase in serum triglycerides. The pre-beta-lipoproteins were at 50 % on day 5 which along with high triglycerides and normal cholesterol made PS a Type 4-lipoprotein phenotype.

It should be noted that blood samples were taken from subject PS 12 days (physical examination) and 3 days before the confinement period began. On both days the serum triglycerides were slightly under 100 mg/ml which supports the assumption that the normal triglyceride values of this subject were within the standard range. At this time it was decided that in future experiments blood samples would be taken from all subjects daily. The dashed line for subject CS in Figure 11 will be discussed later.

Serum triglycerides for the remaining eight subjects are shown in Figure 12. Subjects BR and MY were the first of these eight subjects to participate. Data were not available for subject MY on day 2. A general upward trend in the serum triglycerides for both subjects started in the pre-exposure control period and continued until a maximum was reached on the second day after termination of the alternating magnetic field. These maximum triglyceride values are well above the normal range; however, the corresponding cholesterol levels were normal. Subject BR was clearly a Type 4 phenotype while MY was a borderline case.

The results gained from BR and MY raised the possibility that some aspect of the experimental environment or procedure might be producing a cumulative effect. To rule out this possibility the next two subjects, LS and WD, were used as controls with the procedure and environment maintained as previously except that the coils were not energized at any time. The subjects did not know that they were serving as controls. The control data are identified by dotted lines labeled LS and WD in Figure 12. LS and WD returned separately at later dates for a shortened 4-day experiment. Since their control data were available to serve as pre-exposure baselines, the field was energized on the first day of their confinement (day 3 in Figure 12). Effects and recovery, if any, could then be observed during the remaining 3 days. The experimental data for subject LS did not indicate any effect of the ELF magnetic field nor did his control data suggest any cumulative effects. The experimental data for subject WD showed an upward trend as previously observed in subjects BR and MY but to a lesser extent; however, his control serum triglyceride levels ranged within substantially the same values covered by his exposure data. Two conclusions can be drawn from the combined control and exposure data of these two subjects: normal serum triglycerides may vary considerably from day to day, and the control environment has no cumulative effect on the triglyceride level.

The next group of subjects, PO and FA, had serum triglyceride changes that strongly suggested an effect of the ELF magnetic field (Figure 12). For subject FA the change was seen first in the sample taken 48 hours after exposure. Although this increase was still

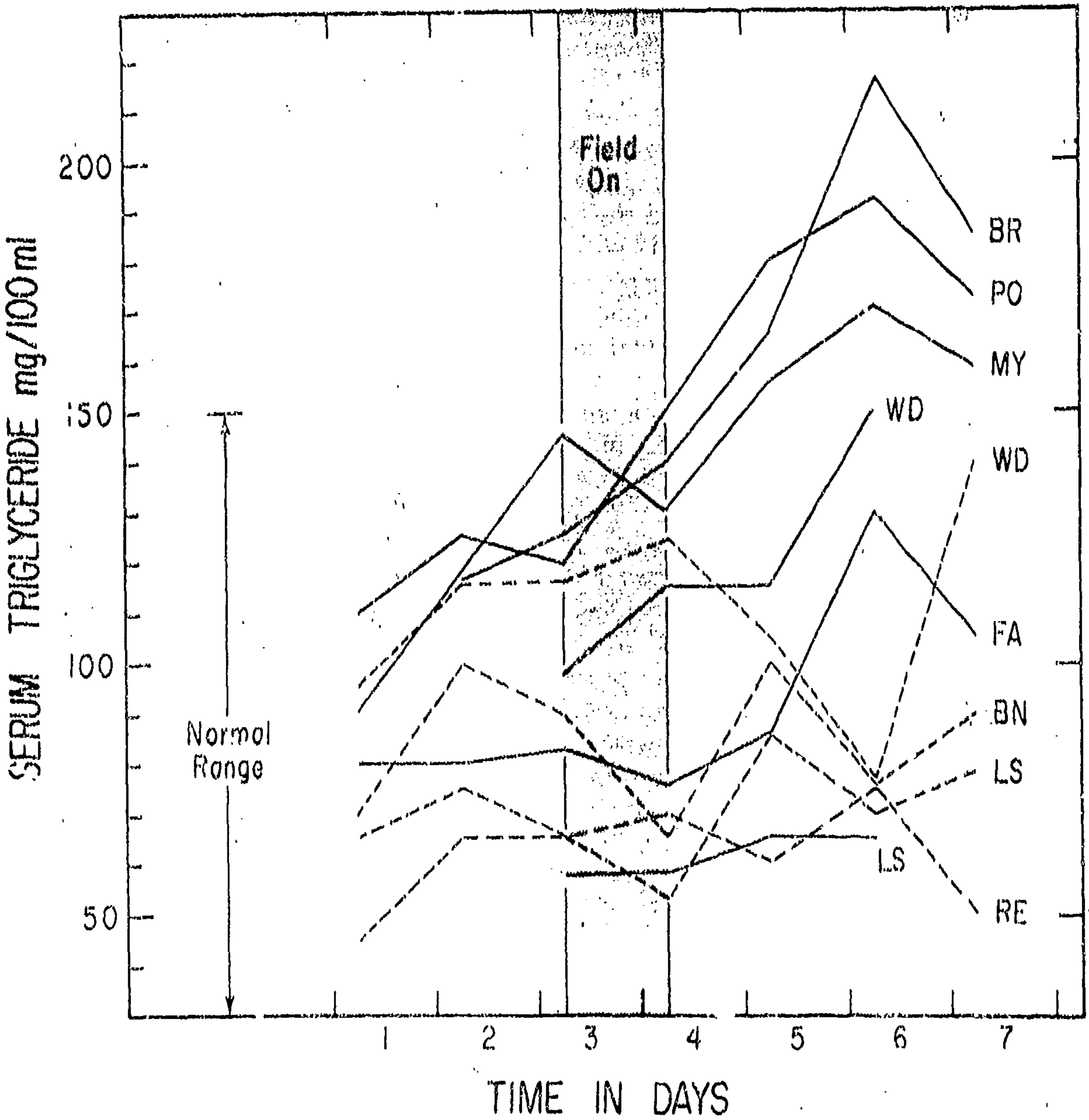

Figure 12

Serum triglyceride levels for four control subjects (dashed lines) and six experimental subjects.

within the normal range, it contrasted sharply with the small variations seen during the previous 5 days. For subject PO, the triglyceride level began to show an increase with the sample taken at the end of exposure and reached a maximum 48 hours after exposure. Forty-eight and 72 hours after exposure the pre-beta-lipoprotein levels for PO were 35%, which, in combination with the triglyceride levels, indicated a Type 4 lipoprotein phenotype for these two samples.

The dashed line in Figure 11 represents data for control subject CS, who was run under the same protocol as the control subjects in Figure 12. His serum triglycerides were so high that it was necessary to plot the data on the scale of Figure 11. CS had a partner, BN, whose data appear in Figure 12 with those of control RE who was run alone. Data from these three control subjects supported that of the other two controls; serum triglycerides did not change significantly during the experiment, and no evidence of a cumulative or general confinement effect was indicated.

The results are summarized in Figure 13. The solid line represents the average daily triglyceride values for four subjects, BR, PO, MY, and FA. Exposed subjects WD, LS and PS were not included because their confinement period was only 4 days as compared to 7 days for the others. The data of subject SN were not used because of abnormalities which were first noted during this subject's pre-experiment tests. The broken line represents the average triglyceride levels for the four control subjects, WD, BN, LS, and RE. The data of CS, the fifth control subject, were not used since they exceeded the normal range. The data from the selected eight subjects were used in the following way for a test of significance. Data from the exposed subjects on days 1, 2, and 3 were combined to form a pre-exposure experimental group. Data from the exposed subjects on days 4, 5, 6, and 7 formed a postexposure experimental group. At the 98% level, the pre-exposure group was found to be from a different population than the postexposure group. A similar test for the control subjects showed the group for days 1, 2, and 3 to be in the same population as the group for days 4, 5, 6, and 7.

RESPIRATORY GAS ANALYSIS AND PHYSICAL STRESS

Respiratory quotients for basal conditions were calculated and plotted for each subject throughout the confinement period. During the exposure period, five subjects showed increased respiratory quotients and two showed decreased respiratory quotients. These changes were not consistent in trend nor different in magnitude from changes for control subjects during the confinement period. The data indicate that the previously discussed changes in serum triglycerides could not have been caused by a change in the proportion of fats and carbohydrates being oxidized.

Results of the exercise test were complicated by variations in physical fitness among the subjects. Subjects in good physical condition had a consistent physiological response throughout the entire test period. Subjects in poor condition were inconsistent in their response patterns, thus making it difficult to compare pre exposure with postexposure data. Physically fit subjects showed no significant changes.

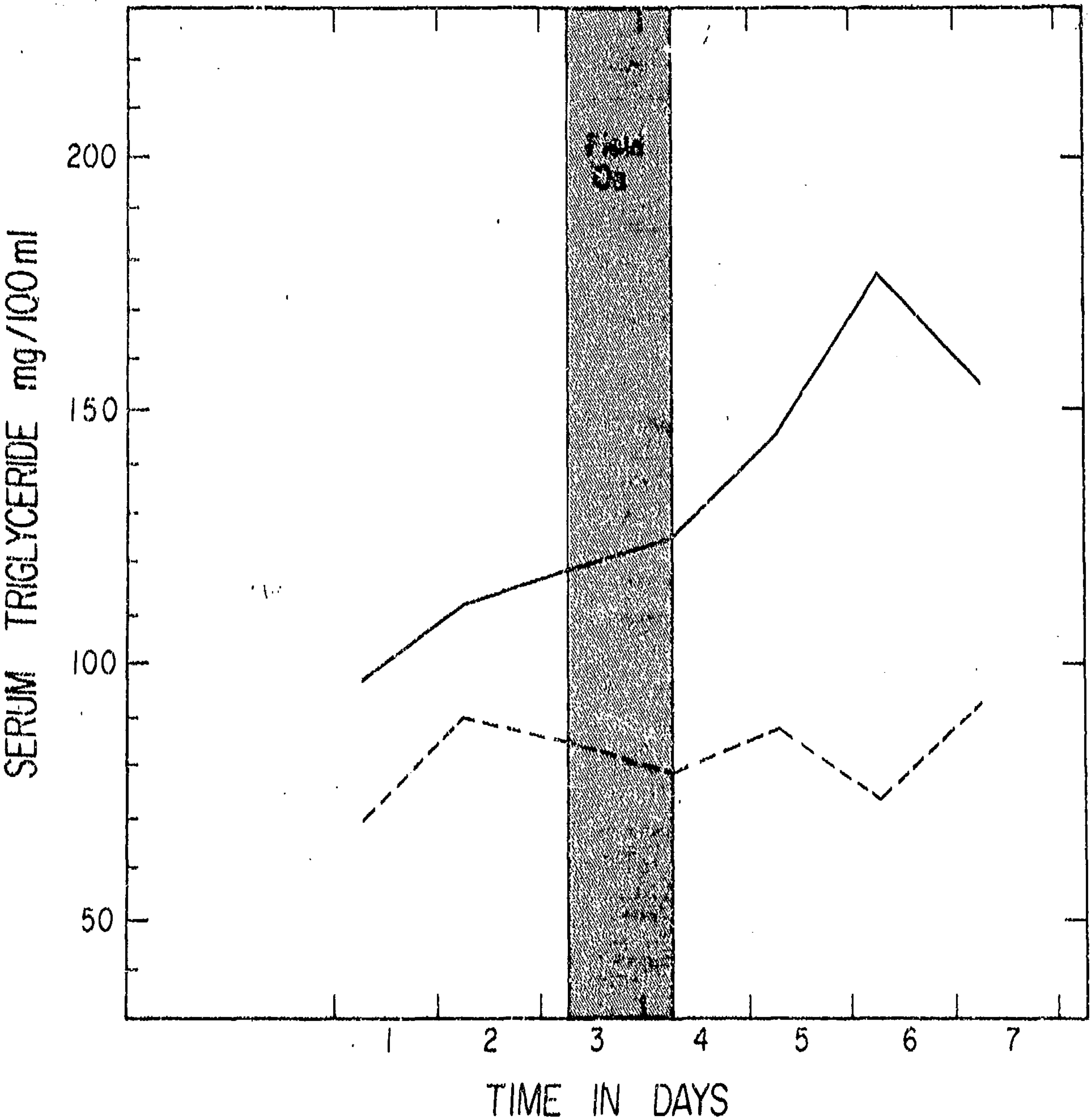

Figure 13

Average serum triglyceride levels of exposed and control subjects. The solid line represents the average daily triglyceride values for four exposed subjects (BR, PO, MY, and FA). The broken line represents the average triglyceride levels for the four control subjects (WD, BN, LS, and RE).

REACTION TIME, PUPILLOGRAPHY, AND SCFF

These three tests were included to provide an indication of mental alertness and showed no consistent trends that could be correlated with the field. One exposed pair, PO and FA, however, showed a significant increase in alertness, as measured by pupillography, on the morning of the fifth day, 24 hours after exposure. On the previous evening these subjects had an argument resulting in a high state of arousal which was still present the following morning, and this appears to be a probable explanation for the increased state of alertness.

DISCUSSION

The present series of experiments should be considered as the beginning of an extensive research effort to find and characterize possible physiological and psychophysiological effects of ELF fields on man. The variables of the physical environment, an alternating magnetic field, were limited to one frequency (45 Hz), one field strength (10^{-4} Wb/m^2), and two values for the exposure time (8 hours and 24 hours). On the other hand, a wide variety of medicobiological methods were applied to make a sweeping search for any effects the field might have on physiological functions or the behavior of man.

The selection of some tests was influenced by two Soviet publications. Vyalov et al. (26) examined 96 persons exposed for periods up to 15 years under industrial laboratory conditions to the 50 Hz field of electromagnets and solenoids, as well as to constant magnetic fields at field strengths between 15 and 420 mWb/m^2. Most of the observed workers exhibited slight departures from the normal health indexes. Most frequently they indicated changes in the nervous system, mainly in autonomic functions. Incidents of headache, increased fatigability, physical weakness and perspiration were also reported. Changes in the EEG were noted, and electrocardiographic data indicated signs of sinus bradycardia and an increase of the T wave in some workers. Similar observations were made by Asanova and Rakov (3) in a field study of 45 persons working at two Volga power stations. The electrical field strength varied between 4 and 26 kV average potential with no magnetic field strength recorded. A probable value may be assumed to be less than 10^{-4} Wb/m^2. Functional disturbances of the central nervous system were determined in more than half of the examinees, and a mild neuroasthenic syndrome was observed in four cases (headaches, fatigue, irritability and tremor of the fingers). Functional disturbances of the cardiovascular system and of peripheral blood were also reported.

Methods in the present study were selected specifically to find an indication of the asthenic syndrome described in both Soviet studies. The findings of reaction time, pupillography, critical flicker frequency and the results of the four psychological tests, however, were generally within the normal range during exposure to the alternating magnetic field, and during a 3-day control period after exposure. The same statement can be made for the results of the electrocardiographic study: No irregularities in the performance of the cardiovascular system were observed during or after exposure to the magnetic field.

The negative findings in the present report as compared to those of Vyalov et al.(26), probably result from the use of a much lower intensity field and considerably shorter exposure periods. In the case of Asanova and Rakov (3), the magnetic fields were probably comparable to the ones used in this study. Their exposure time was longer, however, and a very high alternating electrical field was present in addition to the magnetic field. In this context it is interesting that in a careful study of 11 linemen Kouwenhoven (17) found no physiological or psychological effects of high tension fields with characteristics similar to those investigated by Asanova and Rakov. The results of all laboratory studies were entirely normal.

In a discussion of the unexpected lipid changes observed in this study it should be emphasized that the observations were made on a small number of people and that the results should not be regarded as final or conclusive. Only a full-scale investigation of the effects of alternating fields on lipid metabolism will assess the value of the initial observations.

A search for similar observations by other investigators led to some interesting publications. Pautrizel et al.(22) exposed rabbits on a high cholesterol diet to alternating magnetic fields with the actual field conditions not well defined. Total serum lipids and certain components thereof were analyzed weekly, and at the end of the experiment the extent of plaque formation in the aorta was assessed. After 5 weeks of field treatment, the investigators found a considerable reduction of cholesterinemia and a reduction of plaque formation as compared with controls. This remarkable effect persisted for 5 more weeks after field treatment was interrupted. A similar reduction of blood cholesterol in man was described by de la Warr and Baker (4). After repeated local application of an alternating magnetic field of approximately 10 mWb/m^2 and 40 to 4000 Hz to selected parts of the human body, a sort of "magnetic acupuncture," the serum cholesterol of 10 normal persons was reduced significantly (average reduction of 50 mg/100 ml).

In their medical evaluation of personnel working for 1 year near an ELF transmitting antenna, Krumpe and Tockman (18) observed a statistically significant number ($p < 0.05$) of both control and exposed subjects with decreases in cholesterol and increases in triglycerides. These apparent trends, however, were attributed to changes in the laboratory's methodology between the initial and the follow-up examination.

In the present study no significant change of serum cholesterol was observed during exposure to the field or during a 3-day period thereafter. However, serum cholesterol should be watched carefully in future investigations.

Two other studies should be mentioned which do not specifically concern fat metabolism in animals exposed to magnetic fields. Jitariu (14) exposed dogs, rabbits and guinea pigs for periods up to 15 days to a field of 50 Hz generated by a Magneto-Diaflux apparatus (no field strength given but probably within the range of 10 mWb/m^2). He found significant variations of the K, Na, Ca and Mg ions in serum which he explained as a change in membrane permeability. Similar electrolyte changes have not been found in the present study. Jitariu also found that oxygen consumption of hen eggs exposed

during incubation to the alternating magnetic field was significantly higher than in control experiments. An increase of basal metabolism was not observed in the present study.

Kolodub and Yevtushenko (15) exposed rats to a pulsed magnetic field (one pulse of 130 milliseconds duration in 10 second-intervals) with a frequency of 5-50 kHz and a field strength of 30 to 90 mWb/m^2 in chronic effects' studies during 6 months with a daily exposure of 1.5 hours. A strong disturbance of the carbohydrate and nitrogen metabolism was observed in various tissues and traced to a shortage of ATP and creatine phosphate. Kolodub and Yevtushenko stated that under the influence of the pulsed magnetic fields oxidative phosphorylation suffers. Also, disturbances in the activity of a number of enzymatic systems develop which lead not only to functional disorders but also to well-expressed morphological changes in the internal organs. The experimental fields of their study differ strongly from the fields used in the present investigation, but the suggestion that enzyme action may be sensitive to alternating magnetic fields may be applicable to both.

The increase of serum triglycerides after exposure to the fields used in the present study suggests a change in the activity of one or several enzymes involved in lipid homeostasis. Most suspect is triglyceride lipase which is involved in the removal of lipid material from the serum at the level of adipose tissue. A decrease in enzyme activity or concentration would lead to an accumulation of triglyceride in the serum. Hyperthyroidism which could also produce similar lipid changes was not indicated by measurements of T-3 uptake and T-4 concentration.

The latency of the hyperlipemia, with a maximum triglyceride level observed 1 to 2 days after field exposure, may offer a clue to the mechanism of the field effect. The field may not influence the activity of the enzyme itself but may elicit a decrease in the production of a precursor which is felt only after existing enzyme stores have been depleted. Further speculation would be premature; however, numerous observed effects of weak magnetic fields on chemical reactions in colloidal systems (24) do indicate that specific effects on human lipid metabolism are possible.

An effort was made to assess other environmental components for their influence on the development of hyperlipemia. Confinement of the subjects for approximately 1 week was suspect. Three methods of control were used to assess the effects of confinement: eight subjects served as their own controls with baselines established from pre-exposure data; five subjects served only as controls; and two subjects served in both capacities at different times. Even though serum triglycerides for two of the exposed subjects increased from the beginning of confinement, the absence of an effect on the subjects who served only as controls excludes confinement as a major factor in hyperlipemia induction. In addition, a separate NASA study (21) showed that serum triglycerides were not affected by confinement.

Other factors for consideration were the transfer of the subjects from their usual environment to laboratory conditions. This environmental change may not appear traumatic to investigators who move routinely between home and laboratory, but it may influence some of the uninitiated subjects. Their previous diet and personal habits may have been

drastically different from regulated laboratory conditions. Evidence of this was seen in two subjects; SN was a compulsive eater and DY usually slept less than 6 hours per night before joining the test group. Subsequently, SN's serum triglyceride level dropped when he was restricted to normal meals, and DY's state of alertness improved during the experiment when he received 8 hours of sleep each night. The influence of such factors on the performance of some control and exposed subjects averaged out for many tests but could lead to misinterpretations in a small sample number.

The influence of fear caused by the drastic change in environment, the performance of unknown tests, and the actual exposure to the field were assessed. Gordon and Gordon (7) observed a rapid increase in plasma unesterified fatty acids in man during fear caused by psychic stimuli. Since unesterified fatty acids were not determined in the present study, a comparison cannot be made, but if the factor of fear were present, it should have influenced the lipid metabolism the same way in both the control and exposed subjects. It should be stressed that the subjects were unaware of the time of field activation, and any "fear reaction" to the field should have been present during the entire experiment.

In a recent study Schmitt and Tucker (25) found that under some conditions subjects could sense the presence of a 60-Hz magnetic field or detect subtle clues incidental to its generation. Some individuals were more successful at this than others. In the present study the subjects assured the investigators after the exposure that at no time did they sense the presence of the field, and their guesses were usually far off the actual field condition. The higher field (10^{-3} Wb/m^2) used by Schmitt and Tucker may have caused a field sensation, or clues may have been stronger than in the present study.

Finally, the diet of the subjects merits a remark. The subjects were given free choice from a 2500-calorie hospital diet menu, and no additional food was allowed. Liquid intake was in the form of coffee, tea and fruit juices. The daily fat consumption of each subject may have differed, but such slight differences should average out for control and exposed subjects. Blood samples were drawn after the postprandial serum triglyceride maximum should have been reached, so differences in meals should not have influenced the results.

Barring the oversight of a crucial factor, the results of the present study strongly indicate that certain mechanisms of lipid management in the human body are influenced by an external, comparatively weak alternating magnetic field of low frequency. The final proof of a cause-effect relationship between the exposure to an ELF magnetic field and a biological response depends on the establishment of a correlation between the magnetic field strength and the biological effect and the finding of a threshold. Numerous experiments will be necessary to establish this correlation, and it is desirable to find a mammal with lipid metabolism similar to man. Such attempts are in progress, but the final proof will rest on the exposure and test of man himself.

In future experiments the effects of other extremely low frequencies should also be investigated. Obviously, the world power frequencies of 50 Hz and 60 Hz should claim

special interest since the magnetic fields generated by many electrical household appliances are higher than the 10^{-4} Wb/m^2 field used in the present study, e.g., electric heating pad (2×10^{-4} Wb/m^2). Because of the close association of hyperlipemia with the etiology of arteriosclerosis, an investigation of the possible contributing role of electrical utilities should be of considerable interest. This influence of the magnetic field, if substantiated, may have been overlooked previously because the field-induced hyperlipemia appears to be delayed by several days.

In summary, the results of this pilot study suggest that an alternating magnetic field of 45 Hz and 10^{-4} Wb/m^2 strength may cause a time-delayed increase of serum triglycerides in man. It should be emphasized that the number of subjects was small and that a final assessment depends on establishment of the threshold for the effect and the field strength-biological effect relationship.

REFERENCES

1. Anonymous, Classification of Hyperlipidemias and Hyperlipoproteinemias. Bulletin of the World Health Organization, 43:891, 1970. Cited in Circulation, XLV: 501-508, 1972.

2. Altmann, G., The physiological effect of electrical fields on organisms. Arch. Met. Geoph. Biokl. Ser. B, 17:269-290, 1969. (German)

3. Asanova, T. P., and Rakov, A. N., Health condition of workers exposed to an electrical field of 400-500 kilovolt open distributing installations. Gigiyena Truda I Professional'nyye Zabolevaniya, No. 5:50-52, 1966. Translation: Joint Publication Research Service 36,843 (1966).

4. de la Warr, G. W., and Baker, D., Biomagnetism: Preliminary Studies of the Effect of Magnetic Fields on Living Tissue and Organs in the Human Body. Oxford, England: DelaWarr Laboratories, Ltd., 1967.

5. de Lorge, J., Operant behavior of rhesus monkeys in the presence of extremely low frequency-low intensity magnetic and electric fields: Experiment 1. NAMRL-1155. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1972.

6. Friedman, H., Becker, R. O., and Bachman, C. H., Effect of magnetic fields on reaction time performance. Nature, 213:949-956, 1967.

7. Gordon, P. V., and Gordon, R. S., Rapid increase of plasma unesterified fatty acids in man during fear. J. Psychosomatic Res., 4:5-9, 1959

8. Grissett, J. D., and de Lorge, J., Central-nervous-system effects as measured by reaction time in squirrel monkeys exposed for short periods to extremely low-frequency magnetic fields. NAMRL-1137. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1971.

9. Grissett, J. D., Exposure of squirrel monkeys for long periods to extremely low-frequency magnetic fields: Central-nervous-system effects as measured by reaction time. NAMRL-1146. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1971.

10. Grissett, J. D., A new technique for measuring scotopic critical flicker frequency to indicate psychophysiological stress. NAMRL-1052. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1972.

11. Grissett, J. D., New technique for analyzing reaction-time histograms to indicate psychophysiological stress. Paper presented at Las Vegas, Nev.: 44th Annual Meeting, Aerospace Medicine Association, 1973.

12. Grissett, J. D., Technique for reducing the ambient electric field generated by inductive voltages in low frequency magnetic field generators. NAMRL-1177. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1973.

13. Hamer, J. R., Effects of low level, low frequency electric fields on human reaction time. Commun. Behav. Biol., Part A, 2:217-222, 1968.

14. Jitariu, P., On the action of magnetic fields on the animal organism. Rev. Roum. Biol. Zoologie, Bucarest, 11:3-24, 1966. (French)

15. Kolodub, F. A., and Yevtushenko, G. I., Biochemical aspects of the biological effect of a low-frequency pulsed electromagnetic field. Gigiena Truda I Professional'nyye Zabolevaniya No. 6, 1972. Translation: Joint Publication Research Service 56,583 (1972).

16. König, H. L., The environmental influence of low frequency electrical processes in the atmosphere. Z. angew. Bäder-und Klimaheilkunde, 9:481-501, 1962. (German)

17. Kouwenhoven, W. B., Langworthy, O. R., Singewald, M. L., and Knickerbocker, G. G., Medical evaluation of man working in AC electric fields. IEEE Translation PAS 86:506-511, 1967.

18. Krumpe, P. E., and Tockman, M. S., Evaluation of the health of personnel working near Project Sanguine Beta Test Facility from 1971 to 1972. Research Project Report No. MF12.524.015-0010BE7X, Bureau of Medicine and Surgery. Great Lakes, Ill.: Naval Medical Research Unit No. 4, 1972.

19. Leon, L. P., Rush, R. L., and Turrell, J., Advances in Automated Analysis. Technicon International Congress, 1970.

20. Lowenstein, O., Feinberg, R., and Loewenfeld, I. E., Pupillary movements during acute and chronic fatigue. Invest. Ophthal., 2:138-157, 1963.

21. Neptune, E. M., Jr., Danziger, R. E., Sallee, T. L., and Uddin, D. E., Some biochemical determinations on serum from crewmen participating in a 90-day space station simulator test. In: Preliminary results from an operational 90-day manned test of a regenerative life support system. NASA SP-261. Washington, D. C.: National Aeronautics and Space Administration, 1971. Pp. 573-581.

22. Pautrizel, R., Priore, A., Dallochio, M., and Crockett, R., Influence of electromagnetic waves and magnetic fields on the lipid modifications induced in the rabbit by feeding a hypercholesteremic diet. C. R. Acad. Sc. Paris, (D), 274: 488-491, 1972. (French)

23. Persinger, M. A., Ludwig, H. W., and Ossenkopp, K-P., Psychophysiological effects of extremely low frequency electromagnetic fields: A review. *Percep. and Motor Skills*, 36:1131-1159, 1973.

24. Piccardi, G., *The Chemical Basis of Medical Climatology*. Springfield, Ill.: C. C. Thomas, 1962.

25. Schmitt, O. H., and Tucker, R. D., Human perception of moderate strength low frequency magnetic fields. Washington, D. C.: International Magnetics Conference, sponsored by Magnetics Society, IEEE, April, 1973.

26. Vyalov, A. M., Shpil'berg, P. I., Ushkovich, L. B., Listchkina, Z. S., Ryabova, A. P., Dmitriyeva, K. A., Sokolov, S. A., and Zvonilova, L. D., On the problem of the effect of constant and variable magnetic fields on the human organism. *In:* A. P. Shitskova (Ed.), *Occupational Pathology*, Ministry of Health, Moscow, 1964. Pp. 169-175. Translation: Joint Publications Research Service 36,192 (1966).

27. Yoss, R. E., Moyer, N. J., Carter, E. T., and Evans, W. E., Commercial air-line pilot and his ability to remain alert. *Aerosp. Med.*, 41:1339-1346, 1970.

28. Yoss, R. E. Moyer, N. J., and Hollenhorst, R. W., Pupil size and spontaneous pupillary waves associated with alertness, drowsiness, and sleep. *Neurol.* *20*:545-554, 1970.